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of

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for

# METHOD OF INCREASING THE BOUNDARY LAYER STRENGTH ON SURFACES OF WORKPIECES MADE OF BRITTLE HARD MATERIALS

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Title Of Invention

# METHOD OF INCREASING THE BOUNDARY LAYER STRENGTH ON SURFACES OF WORKPIECES MADE OF BRITTLE HARD MATERIALS

## Cross-Reference To Related Applications

The application is a continuation in part of copending application serial number 09/319,433 for a "Method of Increasing the Boundary Layer Strength on Surfaces of Workpieces Made of Brittle Hard Materials" filed July 27, 1999.

## Field Of The Invention

**[0001]** The present invention relates to method of increasing the boundary layer strength of workpieces manufactured of brittle, hard materials.

## Background Of The Invention

**[0002]** The requirement of a maximum in process reliability in material-processing installations and the ever increasing pressure of cost in the field of maintenance and servicing of units in installation and purchase of new units are the principle reasons for the grown demands on bearing technology, for instance in agitating or stirring machinery and in pumps. Pumps should be useable over a wide range of temperatures and with a variety of lubricants, which could result in contamination. Additional requirements arise in view of suitability for dry running and media lubrication, along with the required long service life and low-cost cost/performance ratio.

**[0003]** Ceramic materials satisfy the aforementioned requirements in particular, which are used, for instance, in the production of bearings such as

rolling bearings and friction bearings. In addition to the wear phenomena, which are only slight, the high temperature resistance of ceramic materials plays an important role in the application of such materials.

**[0004]** One essential aspect regarding the application of brittle, hard materials, which encompass the ceramic materials such as silicon nitrides, is their boundary layer strength, which determines particularly the wear of these materials or the stress and strain to which the materials are subjected. A particularly high degree of boundary layer strength of the individual workpieces is desirable especially for the application as components in mechanical engineering and in terotechnology, which consist of partly or fully ceramic rolling bearings, friction bearings as well as of ceramic elements or ceramic protective layers for which a high resistance to different kinds of wear is required, such as sliding abrasion, wear by blast jet, rolling abrasion or cavitation erosion.

**[0005]** The prevailing understanding as far as the material characteristics of highly brittle materials such as those enumerated above is such, however, that these materials are rated as "exhausted" in terms of their physical properties and that a further increase of their strength beyond the natural strength structure would not be possible and could be implemented only by the application of even more expensive raw materials and manufacturing techniques.

**[0006]** Even though methods are known to increase the boundary layer strength of brittle, hard materials, the achievable success that is obtained with them is not satisfactory. In detail, these methods include thermal and/or chemical treatment processes for influencing the surface characteristics of brittle, hard materials.

[0007] Thermal hardening must be considered to be one of the thermal methods, where the object to be hardened is initially heated and subsequently cooled as shortly thereafter as possible by a so-called "quenching operation." Such hardening methods are preferably applied on glass in an approach to achieve selective superficial tensions in the glass material for a substantial increase of the breaking strength of glass, e.g., optical glasses or automotive windowpanes. However, such an application of thermal hardening on brittle, hard materials encounters substantial difficulties in the case of ceramic materials, because normally so-called thermo shock damage occurs on the ceramic surface, which results in the formation of surface cracks which substantially counteract a possible increase of the boundary layer strength. For this reason practically implementable thermal methods of hardening brittle, hard materials, particularly high-tech ceramics, are not known at present.

[0008] Another possibility to increase the boundary layer strength of ceramics consists in the chemical change of the boundary layer or skin by diffusion treatment with appropriate media or materials. This method, too, has so far been employed only on glass or partly crystalline glass material while the attempt to treat high-tech ceramics by means of "chemical hardening" processes positively for an increase of their boundary layer strength has so far failed. This is because of the very high temperatures and the long periods of treatment necessary to effectuate the hardening process.

[0009] Mechanical methods must be fundamentally mentioned, too, as a third alternative for increasing the boundary layer strength in brittle, hard materials, such as those known in many forms for the treatment of metal workpieces. For instance, metal components are provided with internal superficial compressive strain by means of suitable tools for a mechanical consolidation of the boundary layers, which is a means for increasing the surface strength of such metal components. An appropriate increase of the

strength in brittle, hard materials by a mechanical treatment of the skin or boundary layer has so far neither been known nor been applied in practice without elevating the temperature of the brittle, hard material. Rather, it is presumed that due to the brittle characteristics the mechanical stress produced on the boundary layer of brittle, hard materials rather results in damage -- not an increase of the strength at the surface when the temperature of the brittle, hard material is not elevated.

**[0010]** One conceivable known method of increasing the boundary layer strength of metal components is the shot-peening method, for instance, which results in a plastic deformation of the surface of the components to be processed. In lines 14 and 15 on page 5 of the German patent DE 43 11 319 A1 it is stated expressis verbis, for instance, that the increase of the boundary layer strength which can be achieved on metal components with the application of shot blasts of steel balls is not obtained on ceramic materials because the components would simply be too brittle for resisting the blast energy.

**[0011]** In general, brittle, hard materials such as ceramics are denied to have the ability to undergo a plastic deformation at room temperature. For instance, from the article by J. Kriegesmann "Was ist neu an den Mechanokeramikwerkstoffen?" [What's new about the mechano-ceramic materials?], published in the trade journal "Keramische Zeitschrift," Vol. 39, No. 1, 1997, page 32, left column, the following passage is quoted: "In opposition to metals fracturing occurs already within the elastic range of the stress-strain diagram, however. The mechanical materials characteristic of ceramic materials is hence brittle, which appears to be extremely inexpedient for a mechanical application. If, as a matter of fact, an elastic energy is transmitted to a ceramic material this material tends, in its turn, too, to reduce this energy. Ceramic material, however, has only the capability of achieving this effect by fracturing."

**[0012]** Another quotation is evident from the special issue in the honor of Prof. Eckard Macherauch, ISBN 3-88355-176-7, third paragraph on page 611: "In many cases ceramic materials display a practically purely elastic behavior and are subject to catastrophic fracturing in response to over-critical loads."

**[0013]** Moreover, the following opinion becomes apparent from the contribution by Dr. Pruemmer, "Mooeglichkeiten zur Festigkeitssteigerung von keramischen Werkstoffen durch Oberflaechendruckeigenspannungen" [Possibilities of increasing the strength of ceramic materials by internal superficial compressive strain], published in the trade journal "Keramische Zeitschrift," Vol. 38, No. 9, 1986, right column on page 512: "A compaction of ceramic materials to the extent which is achieved on metallic materials surfaces by cutting processes, grinding and shot-peening, can, as a matter of nature, not be expected in ceramic materials."

**[0014]** Finally, in a article by F. Kroupa in response to a contribution to "International Conference on Advanced Materials and Technologies," June 13 to 16, 1995, Prague (CZ), it is stated: "However, all ceramic materials known to date have insufficient dislocation mobility or maneuverability and the transition temperatures are very high."

**[0015]** U.S. Patent 3,573,023 ("the '023 patent") teaches to treat the surface of a relatively brittle, hard material by shot peening. Concerning the material group of ceramic materials and also glass, the '023 patent teaches to confine the brittle, hard material to a temperature-controllable environment, and elevating the temperature to a level in which material flow is accommodated during the shot peening process (See Col. 2, lines 4-10). Therefore, the '023 patent does not disclose a method for improving the strength of a ceramic without first elevating the temperature of the ceramic prior to applying the mechanical force.

**[0016]** U.S. Patent 5,128,083 ("the '083 patent") discloses a method for modifying the surface of hard engineering ceramic materials, and for sealing the micro surface defects and cracks in the surface of the ceramic material (See Col. 1, lines 30-34). The '083 patent, as in the '023 patent, also requires controlling the atmosphere in which the process is carried out and elevating the temperature to a range of 0.3 Tm to 0.5 Tm (See Col. 2, lines 26-43). Therefore, the '083 patent does not disclose a method for improving the strength of a ceramic without first elevating the temperature of the ceramic prior to applying the mechanical force.

**[0017]** The Abstract of JP041145367 discloses the process of shot peening an alumina article whereby outstanding toughness and breaking strength is obtained. However, the abstract describes a method to enhance the surface toughness of objects made of alumina sintered from and containing a specified amount of Zirconia, which is a transformation toughening material showing a phase transformation induced, for example, by shot peening. This special material, Zirconia, is a very specialized compound, which changes structure from a tetragonal to a monoclinic structure accompanied by an expansion of volume. This expansion takes place at the surface of the object, which leads to internal stresses. Zirconia is the only known compound that shows this effect. Therefore, the Abstract of JP041145367 does not disclose a method for improving the strength of a ceramic without providing an object comprising Zirconia prior to applying the mechanical force.

**[0018]** It is desired to provide a method for improving the strength of a ceramic by applying the mechanical force without having to elevate the temperature of the ceramic

**[0019]** It is also desired to provide a method for improving the strength of a ceramic by applying the mechanical force, where the object to be strengthened does not comprise Zirconia.

## Summary Of The Invention

**[0020]** The present invention is therefore based on the problem of providing a method of increasing the boundary layer strength on surfaces of workpieces made of brittle, hard materials in such a form that the surface strength of brittle, hard materials can be substantially increased by a simple, low-cost processing method. It is the aim to increase the resistance of ceramic workpiece elements used in terotechnology.

**[0021]** In accordance with one aspect of the present invention, a method has been provided for increasing the boundary layer strength of workpieces manufactured of ceramic materials comprising the steps of: providing a workpiece; providing a round contour tool; contacting the workpiece with the tool within a predetermined surface area; producing a plastic deformation on the predefined surface area; and generating internal compressive strain within the workpiece in the vicinity of the predetermined surface area wherein the temperature of the workpiece is not elevated above room temperature and the workpiece does not comprise Zirconia.

**[0022]** In accordance with another aspect of the present invention, a method has been provided for increasing the boundary layer strength of workpieces manufactured of ceramic materials comprising the steps of contacting a workpiece with a tool within a predetermined surface area, wherein the temperature of the workpiece is not elevated above room temperature and the workpiece does not comprise Zirconia.

**[0023]** The invention and its particular features and advantages will become more apparent from the following detailed description.

## Detailed Description Of The Drawings

**[0024]** A method of increasing the boundary layer strength on the surfaces of workpieces made of brittle, hard materials is so designed that the workpiece surface is contacted with a tool within a predetermined, narrowly limited surface area, in which a tool produces an exclusively plastic deformation of the surface area and generates internal compressive strain within the workpiece in the vicinity of the surface.

**[0025]** The present invention is based on the unforeseen finding that an increase of the boundary layer strength by mechanical treatment on the surface is possible on brittle, hard materials, without the necessity of elevating the temperature of the brittle, hard material. It was also found to be possible to increase of the boundary layer strength by mechanical treatment on the surface of brittle, hard materials, without the necessity of utilizing Zirconia, a very specialized compound, to comprise the brittle, hard material. It was possible, for instance, to demonstrate that a workpiece made of silicon nitrite could be processed by plastic deformation on its surface with application of shot-peening methods in such a way that an increase of the boundary layer strength of 15% could be achieved.

**[0026]** The mechanical method of increasing the boundary layer strength of brittle, hard materials, particularly ceramic materials, is based on the fact that regions in the vicinity of the surface are subjected to local plastic deformation produced by an appropriate tool and that internal superficial compressive strain is generated that can counteract the loads occurring in operation, such as those prevailing when rolling bearings made of ceramic materials, for instance, are employed. Essential to the performance of the

mechanical surface treatments is during the generation of plastic deformations on the surface, the generation of any simultaneous damage in the form of brittle fracture processes in the ceramic surfaces will be avoided, which would produce a strength-reducing effect greater than the strength-increasing effect by "plastification."

**[0027]** The aforementioned requirement is satisfied when first, the plastic deformation is restricted to a predetermined laterally narrowly limited surface area and second, the tool presents a defined contour in the region of the contact area that, when described in general terms, must be rated as non-sharp-edged.

**[0028]** The material-specific contour limit depends on the shape of the tool for the contact area between the tool and the surface of the workpiece to be processed and on the depth of impression the tool should not exceed. The laterally shifted local surface treatment may be repeated in order to achieve the desired effect by, for instance, selectively applying plastic deformation all over the surface.

**[0029]** The above-described requirement is met when the tool presents a suitable geometry, preferably a round contour and a tool diameter that must not exceed a critical value, which depends on the material of the workpiece to be processed. The critical values for the sphere diameters range from about .1 mm to a maximum of 4 mm. Typical critical value diameters preferably range from about .1 mm to 1 mm. It is imperative that the critical values not be exceeded in order to avoid generation of damage in the form of brittle fracture processes in the predetermined surface during the process. The critical diameter, which is decisive for sphere dimensioning, defines also the predetermined narrowly limited surface area within which the plastic deformation must take place on the surface of the workpiece of brittle, hard material, which is to be machined.

[0030] In addition to the geometric dimensioning of the tools used to machine the surface of the workpieces to be processed - and as an alternative of shot-peening also hammers, nails and rollers should be mentioned - the kinetic momentum acting upon the workpiece surface, particularly in the shot-peening method, plays an important role. The tool geometry as well as the adjustment of the momentum with which the tool hits against the workpiece surface to be machined must be so adjusted that the desired plastic deformation will occur before brittle fraction, which should preferably not occur, which means that the amount of the momentum to be applied should be so dimensioned that the extent of a possibly occurring detrimental brittle fracture will be restricted in such a way that the positive influence of plastic deformation on the boundary layer strength will be predominant.

[0031] For determining the process parameters required for successful operation preferably two preliminary experiments must be performed: On a plate of the material to be treated the dependence of the compression yielding point and the brittle fracture limit on the tool geometry is determined. To this end the static ball thrust test is employed, for instance, which is described e.g. in the article by T. Hollstein et al. "Vollkeramische Baelzlager aus Siliziumnitrit: Anwendung, Auslegung und Optimierung" [Fully ceramic rolling bearings made of silicon nitrite: application, designing and optimization], in: VDI-Reports No. 1151, 1995, pages 3 to 10. A material having at least the same hardness as the workpiece to be treated is selected as tool material. A rounded shape as smooth as possible is selected as tool shape for the contact area between the tool and the workpiece. This preliminary experiment furnishes the required tool geometry and the admissible amount of momentum to be introduced.

[0032] In a second step, the number of admissible repeated sphere impressions per contact area is determined in a dynamic ball thrust test,

without damage occurring on the workpiece surface however with simultaneous plastic deformation of the surface. In this manner, the admissible degree of coverage is defined; i.e., the number of tool impressions per contact area.

[0033] Subsequent to the determination of the above-described process parameter, the region on the workpiece of brittle, hard material is treated, for instance, by a shot-peening method. Endangered corners and edges of the workpiece that should not be treated must be protected from damage by means of suitable masks.

[0034] The spherical elements impinging on the workpiece surface may be cast onto the workpiece surface with an adjustable kinetic momentum by means of compressed air in a blasting installation or by means of an airless blasting drive so that any point on the workpiece surface to be machined will be hit once or several times.

[0035] Although the invention has been described with reference to a particular arrangement of parts, features and the like, these are not intended to exhaust all possible arrangements or features, and indeed many other modification and variation will be ascertainable to those of skill in the art.